Scenario Design for the Empirical Testing of Organizational Congruence *

David L Kleinman,[1] Georgiy M. Levchuk,[2]
Susan G. Hutchins,[1] and William G. Kemple[1]

[1]Naval Postgraduate School, Information Sciences Dept., 589 Dyer Road, Monterey, CA 93943
[2]Aptima, Inc. 12 Gill Street, Suite 1400, Woburn, MA 01801

ABSTRACT

Over the past several years, researchers within the ONR-sponsored Adaptive Architectures for Command and Control (A2C2) research program have been investigating the concept of organizational "congruence". These model-based theories loosely state that the better an organization is matched structurally to the overall mission (as measured using a multi-variant set of workload/congruence metrics) the better will that organization perform – and that mismatches are potential drivers for adaptation of organization structure.

In order to test the congruence theories and their corollaries in a laboratory experiment, our approach was to seek two sufficiently disparate organizational structures and then design two missions (or scenarios) that would exploit the differences in these two structures. One scenario would be "tuned" to organization 1 to exhibit a high degree of congruence, but at the same time it would be "mismatched" (i.e., exhibit low congruence) with organization 2. Conversely, the second scenario would be engineered to be congruent with organization 1, but incongruent with organization 2. This paper describes the selection of the two organizations, and the model-driven design of the two scenarios.

1. Introduction

In mid-2001 a carrier battle group was underway to its new assignment in the Persian Gulf. Its mission was to perform a presence patrol and to provide naval aviation to conduct Operation Southern Watch. The battle group arrived on location just after the September 11th attack on the World Trade Center and the Pentagon. Thus, its mission was changed significantly – from peacetime presence and Southern Watch to playing a major role in Operation Enduring Freedom. Many aspects of the mission were different: the *tempo* of operations changed from a moderate tempo (where there was time allocated for maintenance and training in addition to flying) to high-tempo sustained operations in support of the troops (Special Operations Force, Marines, Afghani Freedom Fighters, etc.) on the ground. The *mission* had also changed radically: the country of interest was different and the mission tasks were different. That is, the previous tasks that involved countering anti-aircraft systems and an integrated air defense system changed to a totally different set of tasks, i.e., all in support of ground forces.

This actual scenario is but one example of how military forces need to be *adaptable* to accommodate changes in mission that will occur as part of the nature of warfare. In response to this need, the Adaptive Architectures for Command and Control (A2C2) research program integrates optimization, modeling, and simulation-based research efforts with psychology-based and experimental activities to address key issues in command and control. The research has followed a model-experiment-model paradigm wherein models produced by the modeling/simulation efforts support the formulation of hypotheses, the determination of key variables and parameter values, and the prediction of organizational performance and processes of adaptation. The

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14. ABSTRACT
Over the past several years, researchers within the ONR-sponsored Adaptive Architectures for Command and Control (A2C2) research program have been investigating the concept of organizational "congruence". These model-based theories loosely state that the better an organization is matched structurally to the overall mission (as measured using a multi-variant set of workload/congruence metrics) the better will that organization perform - and that mismatches are potential drivers for adaptation of organization structure. In order to test the congruence theories and their corollaries in a laboratory experiment, our approach was to seek two sufficiently disparate organizational structures and then design two missions (or scenarios) that would exploit the differences in these two structures. One scenario would be "tuned" to organization 1 to exhibit a high degree of congruence, but at the same time it would be "mismatched" (i.e., exhibit low congruence) with organization 2. Conversely, the second scenario would be engineered to be congruent with organization 1, but incongruent with organization 2. This paper describes the selection of the two organizations, and the model-driven design of the two scenarios.

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experimental data, in turn, are collected and produced in such a way that allows for both examination of the hypotheses and ease of use by the modelers for post-experimental model-data comparison and model refinement.

One of the major thrusts of the A2C2 research has been the development of models and constructs to design organizations that are matched to a given mission that they plan to perform [Levchuck et al, 2002a, 2002b]. A salient factor that has emerged from this work is the concept of organizational "congruence". These theories loosely state that the better an organization is matched to the overall mission (as measured using a multi-variant set of workload/congruence metrics) the better will that organization perform – and that mismatches are potential drivers for organizational adaptation.

Our approach for testing the congruence theories and their corollaries via laboratory experiment was to *first* seek two sufficiently disparate organizational structures and *then* design two missions (or scenarios) that would exploit the differences in these two structures. In this "reverse engineering" approach one scenario would be "tuned" to organization 1 to exhibit a high degree of congruence, but at the *same* time this scenario would be "mismatched" (i.e., exhibit low congruence) with organization 2. Clearly, the opposite would be necessary for the other scenario.

This paper, along with a companion paper that focuses extensively on the concomitant analytic modeling [Levchuck et al, 2003], describes the selection of the two organizations, and the model-driven design of the two scenarios. Section 2 provides the background that lead up to the experiment; sections 3 and 4 define the overall operational/simulation context that was used; section 5 describes the two organizational structures that were selected; and section 6 gives the details behind the design/crafting of the two scenarios. The experiment – number 8 on the list of A2C2 empirical milestones – was conducted at NPS in August and November 2002.

2. The Road to Experiment 8

Previous A2C2 experiments, and the concomitant models that supported the empirical efforts, focused extensively on the design of organizations that were congruent with a pre-defined mission. Over the course of these experiments, that have spanned 7+ years, the analytical models and the experimentation tools – most notably the Distributed Dynamic Decision-making (DDD) simulator [Kleinman, 1996] – have undergone considerable refinement, improvement, and extension in order to deal with the increasing complexity of relevant C2 issues (e.g., self-synchronization, network-centric operations, time-critical targeting, etc.). Thus, Experiment 8 had a solid basis of previous work to guide its objectives and design, especially the goal to establish the experimental conditions in which the relationship between congruence and performance could be tested.

It was not intended that Experiment 8 would start from "scratch", but would build upon and adapt an earlier context/mission setting to meet our research goals. The setting that we chose to begin from was a DDD experiment that was conducted in March 2001 for the Chief of Naval Operations (N6C) that investigated the processes of self-synchronization in (six-person) functionally-organized versus divisionally/geographically-organized teams. See [Hutchins, et al, 2001]. That experiment was *not* model-driven and employed only a single scenario. In June 2001 the A2C2 research team met to operationalize the basic approach for Experiment 8. It was decided that the organizational dimension would use a functional (F) and a divisional (D) structure suitably modified from those used in the N6C experiment. *Two* scenarios would be designed: one scenario (d) would be congruent with organization D but would be "misfit", or incongruent to organization F. Conversely, the second scenario (f) would be congruent with organization F but misfit to organization D.

Guided by the above operational framework, we undertook to design a preliminary or *concept* experiment [Diedrich et al, 2002], referred to as Concept-8 (C8), which had several purposes. The first was to design and test modifications to the N6C organizations in order to make their structures either more functional or more divisional – i.e., to minimize the degree of commonality/overlap between them in an organizational sense. The second aspect of the C8 experiment was to seek characteristics (in the task dimensions) that make certain tasks more or less difficult for each of the two organizational structures. This was accomplished by examining relative performance on

individual task classes, and via subject post-experiment questionnaire. Another aspect of the C8 work involved the upgrading and testing of the DDD simulator, as a number of features and enhancements were identified as being crucial to the success of Experiment 8. A final aspect of the C8 effort involved identification of measures that would be needed for the model-based analysis of Experiment 8, and the development and introduction of a powerful post-processor tool that would supply the data needed to calculate those measures.

3. Basic Constructs Behind Experiment 8

3.1 Military Context for Experiment 8

Experiment 8 (E8) utilized an underlying military situation similar to that used in the C8 experiment. With reference to Figure 1, Country A has invaded and occupied friendly Country B and has also seized Country B's major port (PORT). Currently, Joint Task Force (JTF) Agile is in position to commence offensive actions to drive Country A's forces out of Country B. If attacked, country A has threatened to use tactical ballistic (SCUD) missiles against island countries D and E that are U.S. allies. In addition it has threatened to mine the sea-lanes to shut down all merchant traffic within the region. Country C is sympathetic to Country A's cause, and could align with Country A in opposing U.S. military actions.

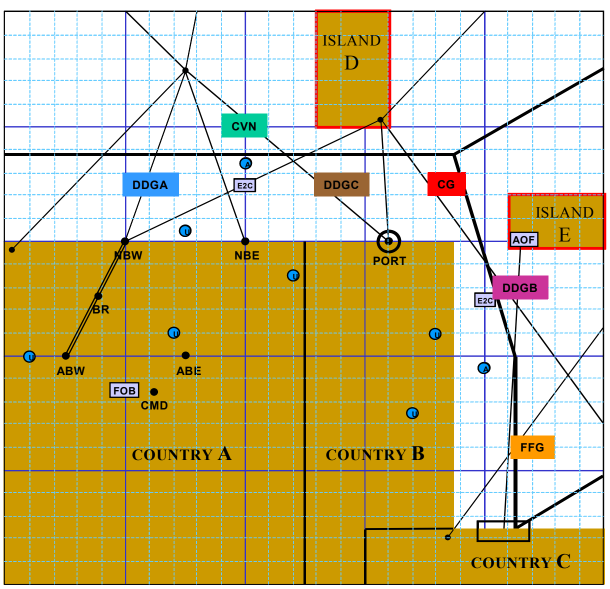

Fig. 1 Experiment 8 Scenario AOR

Country A's forces are concentrated around their naval bases (NBE, NBW) and air bases (ABE, ABW), and are protecting a major bridge (BR). It is likely that the entrances to the naval bases and port have been mined. The enemy has an integrated air defense system that includes aircraft and surface-to-air missiles. They have surface capability in the form of fast patrol boats and missile-firing destroyers. In addition they have placed their coastal defense missiles in positions that give them maximum standoff against U.S. Navy ships.

Joint Task Force Agile's objectives are to establish air and sea dominance in the Area of Responsibility (AOR), to prepare the battlespace for the introduction of follow-on ground forces, to protect our allies in the region from SCUD missiles, and to protect itself (and neutral shipping) from enemy air and sea attack.

3.2 Friendly Forces – JTF Agile

A number of modifications were made to the construct of the JTF based on lessons learned from the C8 experiment. We replaced ASW operations with mine-clearing operations, and replaced the JTF's submarine, which had a limited role due its slow speed, with a third DDG. (Thus, ASW as a warfare area was removed from the simulation.) We increased the role/capability of the FFG (which was somewhat isolated from the core action in C8) by giving this node "control" of an air wing – located at an Air Operations Facility (AOF) on Island E – thereby enabling the FFG to be involved in air defense over a fairly large segment of the AOR. We further modified the JTF by adding Special Operations Forces (SOF), preinserted on a Forward Operating Base (FOB) in Country A, and created relevant offensive ground tasks to be accomplished by the SOF teams. The inclusion of SOF and mine-clearing operations allowed us to increase the richness and complexity of the scenario(s) that would ultimately be designed via the modeling process.

Figure 1 shows the *fixed* location of the six major JTF assets: 3 destroyers (DDGA, DDGB, DDGC), a frigate (FFG), cruiser (CG) and aircraft carrier (CVN), plus the AOF and FOB referred to above. These locations were selected to provide an "optimal" anti-missile shield for islands D and E, to guard the sea lanes (the dark lines in Figure 1) and to be within strike range of key targets in country A. Each platform (or node) contains a

number of *moveable* subplatforms and/or weapons systems. A *subplatform* (e.g., a fixed-wing aircraft, helicopter, UAV, SOF team, etc.) could be "launched" from its parent platform, maneuvered to its objective, but with a finite time duration and weapon load (number of "shots") before having to return for refuel or reload. The *weapons* on a platform (e.g., surface-to-air missiles) are "fire and forget" but are limited in number.

Some of the other information in Table 1 includes the velocity of the subplatforms (mi/min), their endurance or available time, and the number of "shots" each can take before needing to return to its parent for reload. The number of shots is equivalent to the number of tasks that a subplatform can process/attack with a full payload. The velocities are approximately 10X real-world values as the game is played at a 10:1 time scale.

fixed platforms		mi/min	loadout (subplatforms and weapons)
DDGA	Aegis-capable destroyer	0	6SM2, 2HARP, 8TLAM, 4TTOM, 3ABM, 1FAB, 1HH60, 1UAV
DDGB	Aegis-capable destroyer	0	6SM2, 2HARP, 8TLAM, 4TTOM, 3ABM, 1FAB, 1HH60, 1UAV
DDGC	Aegis-capable destroyer	0	6SM2, 2HARP, 8TLAM, 4TTOM, 3ABM, 1FAB, 1HH60, 1UAV
FFG	Aegis-capable frigate	0	4SM2, 2HARP, 1MH53, 1FAB, 1HH60, 1UAV
CG	Aegis-capable cruiser	0	6SM2, 2HARP, 8TLAM, 3ABM, 1MH53, 1FAB, 1HH60, 1UAV
CVN	Aircraft carrier	0	2F18A, 2F18S, 1MH53, 1FAB, 1HH60, 1UAV
E2C	AWACS - aircraft	0	sensors only - prepositioned for total air surveillance in AOR
FOB	forward operating base	0	3SOF teams preinserted in Country A
AOF	air ops facility on Island E	0	2F18A, 2F18S

subplatforms (reloadable)		mi/min	Tavail	# shots
F18A	air-to-air defender	200	15min	2
F18S	air-to-ground strike aircraft	200	15min	1
MH53	helicopter mine clearer	40	60min	2
HH60	search and rescue helo	45	18min	1
UAV	unmanned recon vehicle sensor only	30	60min	n/a
FAB	fast attack boat	25	20min	2
SOF	special ops/SEAL team	40	60min	∞

weapons		mi/sec	range
SM2	standard surface-air missile	5.0	100mi
ABM	anti-ballistic missile	7.0	85mi
TLAM	Tomahawk cruise missile	2.0	360mi
TTOM	tactical/steerable Tomahawk	2.0	500mi
HARP	Harpoon anti-ship missile	1.5	60mi

Table 1: Friendly Order of Battle - Task Force Agile

The asset structure for JTF Agile, that remained *exactly* the same over all runs and all organizations for Experiment 8, is detailed in Table 1. Note that all three DDG nodes have the same load-out: 6SM2, 2HARP, 8TLAM, 4TTOM, 3ABM, 1FAB, 1HH60 and 1UAV. The carrier node has 2F18A, 2F18S, 1MH53, 1FAB, 1HH60 and 1UAV, etc. Allocating the various subplatforms and weapons systems to the major platforms was done with a view towards equalizing the capabilities of the platforms, while still trying to keep these allocations close to "reality", and within the workload limits of players who might be acting as commanders of the major nodes. As will be discussed in Section 5, it is the different distribution of ownership of these various JTF assets among six players that defines the two organizational structures used in Experiment 8.

Some additional information, not shown on Table 1, included the subplatform launch and weapon firing delay, and the duty cycle time between successive launches/firings.

In all of the runs the six (maneuverable) UAVs were pre-positioned in theatre at game start. This avoided the lengthy start-up times as per C8 needed to launch and fly the UAVs into position. In addition to the UAVs, each platform and subplatform (but not weapon) had sensor ability for detecting and identifying air, sea or ground contacts. The sensor ranges for a given asset were generally different for different media, and often depended on the class of contact being sensed.

3.3 Resource Categories and Asset Capabilities

The manner in which we *model* the capabilities of the various assets and weapons has proven itself to be extremely flexible in past efforts. The paradigm

adopted for our model-driven experiments first defines a set/vector of resources R = [r1, r2, …] that is relevant to the problem context at hand. Each element ri defines a resource category or warfare area. Then, every *asset* is assigned a numerical value for each element ri, which defines that asset's resource *capabilities* vector. In addition, each *task* that is contained within the scenario is assigned a vector of resource *requirements*. The paradigm requires the team to prosecute tasks in such a way that a task's resource requirements are met by the summed resource capabilities of the assets allocated to that task. For E8 the selected set of resource categories were:

R = [AAW, Mines, ASuW, BMD, Strike, SAR, SOF]

With these definitions, the capabilities of the assets in JTF Agile are given in Table 2. Note that for this experiment we have elected to use 1 or 0 to indicate whether or not a particular asset (platform, subplatform, or weapon) has capability in any particular resource category, as opposed to using a continuum scale. Thus, a surface-to-air standard missile (SM2) has AAW capability, as does an F18A. [The one exception here is the F18S that has 2 units of STRIKE to indicate that its one attack has twice the "punch" of a TLAM.] In particular note that we have gone to great lengths to give each asset capability in only *one* resource category. While this may ignore the multi-functional capability of some subplatforms, it was done to keep the associated modeling "clean" so that assets would not be considered for use in areas other than in their primary ones.

Name	Description	AAW	Mines	ASuW	BMD	Strike	SAR	SOF
platforms:								
DDGA	destroyer	0	0	0	0	0	0	0
DDGB	destroyer	0	0	0	0	0	0	0
FFG	frigate	0	0	0	0	0	0	0
CG	cruiser	0	0	0	0	0	0	0
CVN	Aircraft carrier	0	0	0	0	0	0	0
DDGC	destroyer	0	0	0	0	0	0	0
E2C	Air survellance a/c	0	0	0	0	0	0	0
subplatforms:								
F18A	Air-to-air defender	1	0	0	0	0	0	0
F18S	Strike aircraft	0	0	0	0	2	0	0
MH53	Mine clearing helo	0	1	0	0	0	0	0
HH60	Search & rescue helo	0	0	0	0	0	1	0
UAV	Pilotless sensor a/c	0	0	0	0	0	0	0
FAB	Fast attack boat	0	0	1	0	0	0	0
SOF	Special Ops unit	0	0	0	0	0	0	1
weapons:								
SM2	Surface-to-air missile	1	0	0	0	0	0	0
ABM	Anti-ballistic missile	0	0	0	1	0	0	0
TLAM	Tomahawk missile	0	0	0	0	1	0	0
TTOM	Tactical Tomahawk	0	0	0	0	1	0	0
HARP	Anti-ship missile	0	0	1	0	0	0	0

Table 2: Asset Resource Capabilities

Another fact to note is that the six primary platforms do not have any *native or organic* capabilities – all of their capabilities derive from their subplatforms and weapons systems. This is a change from C8 where the self-defense of a particular platform using its organic systems became confounded with player roles in a functional organization. Thus, the defense of a platform must now be accomplished by using the various JTF assets located on that platform as well as elsewhere.

4. Mission Task Graph

The greatest limitation of C8 for model-driven experimentation was the fact that there was no mission plan (i.e., task graph) that defined a sequence of tasks or course of action that the JTF was to accomplish. Experiment C8 dealt primarily with destroying enemy forces and self-defense, with no clear statement of what the "mission" objective was. This was a source of complaint by the players, which we sought to remedy in Experiment 8. Moreover, the modeling approach requires a task graph in order to determine the "optimal" allocation of assets to tasks in order to minimize the time span of the mission. Thus, a well-defined mission is a backbone to both the experimental and analytical parts of the Experiment 8 effort, and provides a yardstick to measure the progress of teams as they move along in space and time to complete the mission.

A task graph is basically a mission plan or course of action (COA) that shows the precedence relations among tasks. After considerable adjustment via modeler-experimenter iteration, the task graph that emerged for E8 is shown in Figure 2. Since our objective was to design *two* scenarios, we made the decision that both scenarios would be based on the same task graph, with the salient differences being *only* in the individual task requirements and enemy force dispositions. One of our original thoughts was to construct the two scenarios to have radically different task graphs or

missions (e.g., disaster relief versus amphibious operation). But the reality of needing to train subjects to perform two very different missions in the limited time these players were available to the project made such an approach infeasible – not to mention the time and resources that it would have taken to build a second scenario.

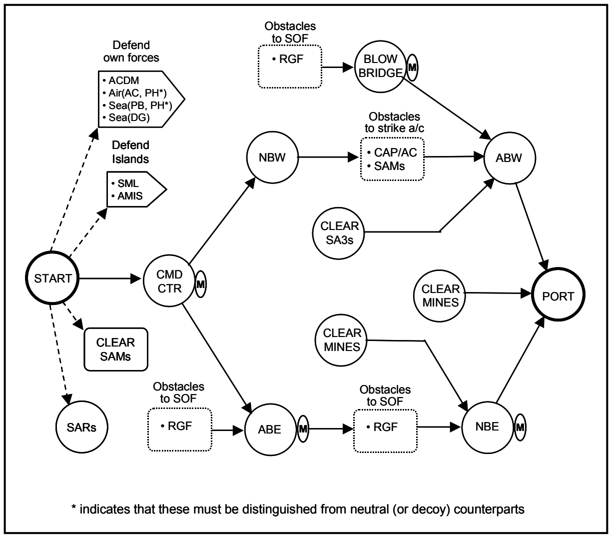

Fig. 2: Mission Task Graph, Experiment 8

The mission tasks are shown as circles in Figure 2. These are the tasks that must be done, are "known" and planned for in advanced, and generally follow a prerequisite structure that establishes a task processing sequence. This course of action or plan first destroys the enemy command center (CTR) and then (with the aid of SOF) captures ABE and NBE that will serve as bases for the introduction of our follow-on air and sea forces. ABE and NBE are likely to be defended by ground forces (RGF) that present obstacles to the SOF teams. In addition, mines at the entrance to NBE need to be cleared. In parallel with the above tasks, first NBW and then ABW are to be destroyed. Prior to destroying ABW it is necessary to destroy a key bridge on the road between NBW and ABW to deny the enemy his ability to reinforce ABW. Mobile SAM sites (SA3) protect ABW. Having completed ABW and NBE, the final objective of securing Country B's PORT can be achieved once the mines have been cleared. Several of the mission tasks, especially those that need SOF to accomplish, may spawn an evacuation of wounded (EVA) as a consequence of performing that task. These medivac/EVA tasks are shown symbolically on the task graph as an M within an oval.

Other tasks shown in Figure 2 are the search and rescues (SARs), which we treat as high priority mission tasks, and the desire to clear SAM sites in the northern half of Countries A and B to allow unhampered use of this airspace. A primary (aggregated) task of the JTF is to protect the island countries D and E from SCUD missile attacks, either by destroying the launchers (SML) on the ground or shooting down the launched missiles (AMIS). The JTF also must protect its own assets from enemy air and surface threats. These aggregated defend tasks are shown symbolically in Figure 2 along with the possible subtasks that make up the higher-level task.

As noted, two scenarios were constructed based on the task graph of Figure 2, where a major factor distinguishing the scenarios was the requirements vector for each of the individual task classes. The development of the two scenarios is given in section 6.

5. Selection of Organizational Structures

The precursor C8 experiment examined both a functional (F) and a divisional (D) six-node organizational structure performing a *single* mission that consisted of a variety of complex tasks. The primary distinctions between the two structures were asset ownership (who owned what) and locus of responsibility. The functional structure was organized such that each commander specialized in a *single* aspect of the mission (e.g. strike or surface warfare) over the entire battle space, controlling relevant assets that were distributed across multiple platforms (ships). By contrast, commanders in the divisional structure controlled a single multi-functional platform (e.g., DDG or CVN) that to a large extent was able to process a variety of functional tasks in only a portion of the battle space. The organizations selected for the current experiment were modifications and refinements to those of C8.

The C8 experiment hinted that testing the congruence theories in an experimental setting would be best served if the "distance" between the two organizational structures (F and D) was maximized to mitigate the inevitable variance when dealing with human teams. Thus, it was prudent to further "separate" the F and D organizations to obtain two extreme cases of these organizational structures. We took guidance from

the research work at Michigan State University that examined a four-person team that was organized across either functional or divisional lines [Hollenbeck et al, 2002]. Thus, we strove to have each node in the D organization have capability in as many functional warfare areas as possible. Likewise, it was desired that each functional node would control associated functional assets (subplatforms or weapons) distributed over all six primary platforms – *with little or no overlap in functional areas among the nodes*.

The selection of assets within the composite JTF and their capabilities proscribes what is capable of being achieved organizationally. These assets – and their allocation to parent platforms as shown in Table 1 plus their capabilities as in Table 2 – were crafted to best allow for building an F and D organization that met the above-noted design goals. Associated with this asset mix is the following set of eight possible functional warfare areas:

AAW = anti-air warfare
Mines = mine-clearing operations
ASuW = anti-surface warfare
BMD = ballistic missile defense
Strike = strike warfare
SAR = search and rescue
SOF = special/ground operations
ISR = intel/survellance/recon

Note that these warfare areas closely follow the categories in the resource vector. An early decision in the design of Experiment 8 was to constrain the organization(s) to six player or decisionmaker (DM) nodes – all at the same level – plus a seventh node (DM0) which represented the CJTF. This was identical to the structure that was used in the previous N6C and C8 experiments. The CJTF was actually present in the experiment but was not involved *actively* in the game play and owned no assets. [However, the CJTF node was a useful element in the training/mission rehearsal trials.] The six-node limit meant that some nodes or players in F would have to assume two hats: We combined Mines with ASuW, and SOF with SAR as these aggregations made the most sense operationally. The D organization was relatively straightforward as each of the six player nodes corresponded to one of the major platforms in Table 1.

With the nodes so defined, the allocation of assets to nodes for both the D and F organizations is shown in Table 3. The divisional (D) organization nodes are shown in the horizontal rows and reflect the assets and weapons on the major platforms. In this organization a player is a *platform commander*. The aircraft "owned" by the FFG are those located on the AOF on Island E. Each of the three DDG nodes "owns" one of the SOF units on the FOB. Note that every node was given capability in most of the eight warfare areas (albeit of a somewhat differing nature) except for the CVN and FFG in BMD, the CVN, FFG and CG in SOF, and the DDGs in Mines. This was done to balance platform loadings so that individual players in D would not be overloaded with (heterogeneous) assets to control. It is also important to bear in mind that many of the capabilities of a particular node in D extend only within its local geographical region due to finite weapon ranges and subplatform endurance times.

	STRIKE	BMD	ISR	AWC	SuWC/MINES	SOF/SAR
CVN	2F18S	xxx	1UAV	2F18A	1FAB 1MH53	1HH60
DDGA	8TLAM	3ABM 4TTOM	1UAV	6SM2	1FAB, 2HARP	1HH60 1SOF
DDGB	8TLAM	3ABM 4TTOM	1UAV	6SM2	1FAB, 2HARP	1HH60 1SOF
CG	8TLAM	3ABM	1UAV	6SM2	1FAB,2HARP 1MH53	1HH60
FFG	2F18S	xxx	1UAV	2F18A 4SM2	1FAB,2HARP 1MH53	1HH60
DDGC	8TLAM	3ABM 4TTOM	1UAV	6SM2	1FAB, 2HARP	1HH60 1SOF

Table 3: D and F Organizational Structures

The functional (F) organizational nodes are depicted vertically in the columns of Table 3. In this organization a player/DM node "owns" all of the assets relevant to his/her warfare area across the entire AOR. Each player, then, is a *warfare area commander*. In addition, the operating environment for the game was such that any player (e.g., Strike Warfare Commander) had the authority to launch aircraft or fire TLAM from *any* platform. It was implicitly assumed that each warfare area commander was "located" on a

particular platform, although this had no bearing on the actual game play. For reference, the Strike Commander was assumed to be located on the CVN, the BMD Commander on the DDGA, the ISR Commander on the DDGB, the AWC on the CG, the ASuWC/MWC on the FFG, and the SOF/SAR Commander on the DDGC.

One of the goals in building the F organization was to have no overlap in capabilities across functional areas. This was largely achieved, as each asset has capability in just one resource dimension as shown in Table 2. However, there were some exceptions: 1) All subplatforms (F18s, HH60, etc.) have some ISR capability; hence ISR is not unique to only the UAVs. We mitigated this overlap in ISR among warfare commanders by emphasizing the role of the UAVs for *ground* ISR within Countries A and B, and reducing the ISR capability of the F18s to detect/identify *ground* contacts. 2) The tactical tomahawks (TTOMs) do have strike capability, yet the BMD commander owns these assets. In the experiment we stressed the importance of the TTOM as the weapon of choice for destroying SCUD missile launchers, and severely limited their number within the JTF to help assure that TTOMs would not be used for "normal" strike operations. Conversely, the scenarios were designed to make it difficult to destroy a SML using a TLAM (that is, it was imperative to have a weapon in the area given the short set-up and fire time of SCUDs), and using an F18S would be "overkill".

6. Scenario Design

As has been noted, the objective was to design two scenarios – each based upon the task graph of Figure 2 – such that one scenario (d) would be congruent with organization D but misfit or incongruent to organization F. Conversely, the second scenario (f) would be congruent with organization F but misfit to organization D. One of the underlying hypotheses that we are testing is that congruence between organization and mission leads to good performance, i.e., organizations that are congruent with their mission will perform better than those that are incongruent.

In this section the design of scenarios d and f are discussed. Several factors drove the design.

6.1 Resource Requirements for Task Classes

The two organizations differed primarily with respect to the assets (and hence the resource/ functional capabilities) that each DM node owned. The congruence model postulates that inter-DM coordination is a major contributor to workload, and that the degree of predicted (structural) congruence is inversely related to the amount of inter-DM (inter-nodal) coordination needed to accomplish the mission. Therefore, by adjusting the resource requirements of selected task classes it becomes possible to manipulate the inter-DM coordination needed to successfully prosecute these tasks for a given organization-scenario pairing. Thus, we set out to design a number of tasks within scenario f such that little coordination would be needed within organization F, while significant coordination would be needed by organization D. The case is reversed for scenario d wherein tasks must be designed to favor D while being mismatched to F. For example, a task requiring a single asset in each of three functional areas would need three DMs to coordinate in F, but could be performed by a single DM in D – provided that he/she owned assets in all of the requisite areas. Similarly, a task requiring multiple assets in a single functional area is well-suited to F, but would need multiple players in organization D to "pool" their assets.

The task classes considered for this coordination manipulation included: (1) all of the key "mission" tasks as shown in the task graph of Figure 2, and to a lesser extent (2) search and rescue, mine clearing, SAM sites and enemy destroyers. To both the f and d scenarios we further added a number of time-critical "pop-up" or unanticipated tasks that have complex resource requirements, such as have the mission tasks. These were high priority tasks that need to be accomplished in a finite time window – e.g. a white merchant ship hitting a mine or coming under attack by hostile aircraft. For each of the f and d scenarios we added between 5-7 such tasks, thereby providing an additional means to further manipulate (in)congruence.

Task Resource Requirements: Scenario d

The list of task classes within scenario d is given in Table 4. There were a total of 35 task classes used in the design of this scenario, where the number of instantiations (i.e., individual tasks) of each class ranged between 1 and 20 depending on the class.

symbol	description	AAW	Mines	ASuW	BMD	Strike	SAR	SOF
NBE	Naval base - East	0	0	1	0	2	0	1
NBW	Naval base - West	0	0	1	0	2	0	0
CMD	Enemy command center	0	0	0	0	1	0	1
DG	Missile-firing destroyer	1	0	1	0	0	0	0
PT	fast patrol/missile craft	0	0	1	0	0	0	0
CDL	coastal defense launcher	0	0	0	0	1	0	0
SML	SCUD msl launcher	0	0	0	0	1	0	0
AC	aircraft attack wave	1	0	0	0	0	0	0
ABE	Air base - East	0	0	0	0	2	0	1
ABW	Air base - West	0	0	0	0	2	0	1
SAM	SAM site - fixed	0	0	0	0	1	0	1
ANU	commercial air	0	0	0	0	0	0	0
SNU	white/merchant ship	0	0	0	0	0	0	0
CDM	CD cruise missile	1	0	0	0	0	0	0
MIS	SCUD-launched missile	0	0	0	1	0	0	0
MIN	sea mines	1	1	0	0	0	0	0
XOC	exocet fired at blue ships	1	0	0	0	0	0	0
APH	*possible* hostile air: Yes	1	0	0	0	0	0	0
APH	*possible* hostile air: No	0	0	0	0	0	0	0
SPH	*possible* hostile ship: Yes	0	0	1	0	0	0	0
SPH	*possible* hostile ship: No	0	0	0	0	0	0	0
SA3	*mobile* SAM site	0	0	0	0	2	0	0
EW	possible SCUD launch	0	0	0	0	0	0	0
S&R	basic rescue effort at sea	0	0	1	0	0	1	0
RGF	red ground force	0	0	0	0	2	0	0
SML	SCUD 2nd msl launcher	0	0	0	0	1	0	0
BR	major bridge	0	0	0	0	2	0	1
PRT	final goal - secure Port	0	0	1	0	2	0	1
TSK	F14 down & under attack	1	0	1	0	0	1	0
TSK	rescue at POW camp	0	0	1	0	2	1	0
TSK	ship hit mine; under attack	1	1	0	0	0	1	0
EVA	evacuate wounded	1	0	0	0	0	1	0
HOS	hostage taker at sea	0	0	1	0	0	1	0
CAP	aircraft attacker/defender	2	0	0	0	0	0	0
SA6	SAM netted cluster	0	0	0	0	2	0	0

Table 4: Task Resource Requirements, Scenario d

An example of how a task's resource requirement differentially drives the coordination demands within D and F is shown by the mission task NBE ("destroy Naval Base East"). This task needs 1 unit of ASuW, 2 units of Strike, and 1 unit of SOF. In the D organization any one of three DDG commanders could accomplish the task *alone*, with *no inter-DM coordination required*. [With reference to Table 3 each DDG "owns" a SOF unit, TLAM strike assets and a fast attack boat (FAB).] On the other hand, *three* players in the F organization – the Strike, ASuW and SOF/SAR warfare area commanders – would need to coordinate to properly process this task. But coordination must have an element of time synchronization if it is to be meaningful in our experimental setting. In the scenario each task had a time window (Tw) within which all of the assets allocated to that task must commence their individual attacks. The NBE had a Tw of 40sec. Once the first asset allocated to NBE begins its attack, a 40sec countdown begins within which time all of the additional assets allocated to NBE must begin their attack. If less than the task's full resource requirements are met the team receives only a partial score on the task. The value of Tw for each task class roughly scaled with the number of assets needed for task processing.

The high-priority (unanticipated) tasks are listed as TSK in Table 4. There were three such classes with two task instantiations in each. Note that the resource requirements span a number of warfare areas, yet in all cases the tasks were designed to be accomplished by a single DM in organization D. In selecting the requirements for these multi-resource tasks, care was taken to assure that the tasks would appear to be "realistic", i.e., requiring assets that *might* normally work together. These TSK tasks (as well as the slightly less complex S&R, HOS, EVA) are *time-critical*, i.e., unlike the mission tasks, they must be accomplished before a deadline or else they "disappear" or expire. This places an added stress upon the players by urging them to react in a timely manner.

Task Resource Requirements: Scenario f

The list of task classes within scenario f is given in Table 5. There were also a total of 35 task classes used here, with most having the same name as in scenario d, but with considerably different resource requirements. For example, the NBW mission task requires six units of strike in this scenario. In the F organization the Strike commander can accomplish this task as a single DM using a combination of F18S (from the CVN or AOF) and/or TLAM fired from any of 4 platforms. On the other hand, in the D organization two or three players must coordinate to synchronize their attack using their strike assets. Note that each DDG or CG commander possesses enough TLAM assets to accomplish the NBE task by himself. However, the NBE's time window of 40s, coupled with an imposed time delay of 23s between successive TLAM launches, implies that no more than two TLAMs from a *single* platform

symbol	description	AAW	Mines	ASuW	BMD	Strike	SAR	SOF
NBE	Naval base - East	0	0	2	0	0	0	2
NBW	Naval base - West	0	0	0	0	6	0	0
CMD	Enemy command center	0	0	0	0	0	0	2
DG	Missile-firing destroyer	0	0	2	0	0	0	0
PT	fast patrol/missile craft	0	0	1	0	0	0	0
CDL	coastal defense launcher	0	0	0	0	1	0	0
SML	SCUD msl launcher	0	0	0	0	1	0	0
AC	aircraft attack wave	1	0	0	0	0	0	0
ABE	Air base - East	0	0	0	0	0	0	3
ABW	Air base - West	0	0	0	0	6	0	0
SAM	SAM site - fixed	0	0	0	0	2	0	0
ANU	commercial air	0	0	0	0	0	0	0
SNU	white/merchant ship	0	0	0	0	0	0	0
CDM	CD cruise missile	1	0	0	0	0	0	0
MIS	SCUD-launched missile	0	0	0	1	0	0	0
MIN	sea mines	0	2	0	0	0	0	0
XOC	exocet fired at blue ships	1	0	0	0	0	0	0
APH	*possible* hostile air: Yes	1	0	0	0	0	0	0
APH	*possible* hostile air: No	0	0	0	0	0	0	0
SPH	*possible* hostile ship: Yes	0	0	1	0	0	0	0
SPH	*possible* hostile ship: No	0	0	0	0	0	0	0
SA3	*mobile* SAM site	0	0	0	0	2	0	0
EW	possible SCUD launch	0	0	0	0	0	0	0
S&R	basic rescue effort at sea	0	0	0	0	0	2	0
RGF	red ground force	0	0	0	0	3	0	0
SML	SCUD 2nd msl launcher	0	0	0	0	1	0	0
BR	major bridge	0	0	0	0	0	0	2
PRT	final goal - secure Port	0	0	2	0	0	0	2
TSK	enemy hidden airbase	0	0	0	0	3	0	0
TSK	enemy shipping blockade	0	0	2	0	0	0	0
TSK	terrorist leader seen	0	0	0	0	0	0	1
EVA	evacuate wounded	0	0	0	0	0	2	0
GUN	gun runners	0	0	2	0	0	0	0
CAP	aircraft attacker/defender	3	0	0	0	0	0	0
SA6	SAM netted cluster	0	0	0	0	2	0	0

Table 5: Task Resource Requirements, Scenario f

can be used to attack NBE. A similar construct exists for most other task classes requiring strike assets. For example, the SAM sites that require two units of strike within a 20s window, must be accomplished via a two-DM coordination in the D organization, but can be accomplished by the Strike Commander in F acting alone.

The resource requirements for the major mission tasks in f were adjusted to require coordination among two or more DMs in D but not in F. Another example of the need for multi-person intra-task coordination is the Air base East (ABE) that needs three DMs to coordinate to satisfy the 3SOF resource requirement. In addition to these mission tasks, the unanticipated and time-critical tasks were crafted to place further demands on team coordination. These tasks are not directly part of the mission task graph to allow considerable flexibility on the location and timing of their appearance in the scenario. When designing the requirements and locations for many of these tasks it became necessary to assure that the tasks could indeed be accomplished (in the time allotted) by the assets that the organization owns! For example, the search and rescue (S&R) tasks require 2 units of SAR; the mine tasks (MIN) require 2 units of MIN, etc. However, the team has a limited number of HH60s (the SAR-capable assets), and MH53s (used for mine clearing). Model-based analysis was used extensively to assure that limited assets could indeed be scheduled to accomplish all of the tasks. For some task classes, timing and location of tasks were modified; for some other classes it was necessary to reduce the number of tasks. To assure that tasks (and even the overall mission) would be accomplished in a reasonable time, asset velocities were increased when necessary. In addition, NPS students "play-tested" both the f and d scenarios to further assure that the design goals were being met, and adjustments were make as necessary.

6.2 Inter-task Coordination

Adjustment of task resource requirements was used as a primary manipulator of intra-task coordination. In addition, *inter-task* coordination was manipulated in the d and f scenarios largely via the task dependency structure as exhibited in the task graph. Successive tasks in the task graph have an implied *information* flow due to their precedence order – task B cannot be started until prerequisite task A is completed. This has implications for asset management as regards the preparation/readiness of assets for the downstream tasks. If successive tasks involve different DMs then information on the status/planning of prerequisite tasks must be passed between DMs, thus requiring inter-DM *information* coordination.

If contiguous pieces of the task graph could be allocated to a single DM (via the design of resource requirements of tasks and their immediate prerequisites) inter-DM coordination would be reduced. To the extent that this was possible, the task graph was built to minimize inter-task coordination by DMs in the congruent situations (Dd and Ff) and to require inter-task coordination among successive tasks in the non-congruent

situations (Df and Fd). For example, in the f scenario (see Table 5 and Figure 2) the lower branch of the task graph has a heavy dependence on SOF assets and is largely allocated to the SOF commander in F; the upper branch is largely under the responsibility of the Strike Commander. In scenario d (see Table 4) the multi-resource tasks were designed so that one of the DDG commanders in D would have the assets and responsibility for the tasks in the east (lower branch); another DDG commander could handle the west (upper branch). Clearly, in the mis-matched or incongruent situations, different DMs are needed to process successive tasks simply as a result of the different resource requirements. While this was not a major manipulation in the scenario design process for this experiment, it can prove to be a very salient mechanism for manipulating congruence in situations that have higher inter-task information flow requirements – especially in those cases where the team does not have a global (common) information structure.

6.3 Spatial-Temporal Loading

The adjustment of arrival times, locations and trajectories of the many task classes that make up the "defend" tasks provides a second powerful mechanism to adjust the f and d scenarios vis-à-vis the two organizations. The resource requirements focussed on manipulating coordination; the spatial-temporal mechanism manipulated (differential) loading among the team's DMs. The task classes that fall into this category include:

AC = enemy air attackers
APH = *possibly* hostile aircraft (about 50% are indeed hostile)
CDM = cruise missiles fired from coastal defense launchers (CDLs)
MIN = enemy mines (except those that are mission task prerequisites)
PT = enemy patrol/missile boats
DG = enemy missile-firing destroyers
SPH = *possibly* hostile surface craft (about 50% are indeed hostile)

The timing and location of sea search and rescue tasks (S&R) were also part of this manipulation. Most of these task classes had simple resource requirements: for example a single unit of AAW or ASuW for AC and PT, respectively. However, each scenario contained a large number (13-15) of such tasks, thereby allowing for the construction of task "waves" to vary the workload for different DMs in a carefully orchestrated manner.

Spatial-Temporal Loading: Scenario d

In scenario d the task "waves" were built to be relatively easy for players in D, while being difficult for players in F. Thus, the waves typically consisted of many tasks with the same resource requirements spread over a broad geographical area – for example a large coordinated enemy air attack that simultaneously targeted a number of fixed platforms. Clearly, this would pose a significant problem for the AWC in organization F not only because of the load but also due to the need to focus on several disjoint areas of the battlespace at the same time. Players in the D organization would not experience as much difficulty in countering this wave since the load would be distributed among several DMs, with each focussing on but a small piece of the AOR.

A number of waves comprising either air, surface, mines or search and rescue tasks were constructed. A wave generally consisted of between 3 and 5 individual tasks, and was spaced roughly every 300s in the simulation so as to minimize overlap with successive waves. Overall there was about two air, two surface, one mine, and two SAR waves. In some cases the waves were adjusted to coincide with time critical (pop-up or unanticipated) tasks that had resource requirements in common with those of the primary wave.

In addition to the adjustment of tasks to overload the AWC, ASuWC, and SOF/SAR commander in F, we also adjusted the arrival times and locations of the SCUD missile launchers (SMLs) in scenario d to make their processing in F more difficult. Their appearances were such that SMLs arrived in pairs, in separated areas within countries A and B. It was expected that this would be more problematical for the ISR and BMD commanders in F than for two players in D where each one was concerned with only a single geographical area.

Spatial-Temporal Loading: Scenario f

In scenario f the task "waves" were built to be relatively easy for players in F, while being difficult for players in D. Thus, a wave typically consisted of a number of tasks with *different* resource requirements focussing on a narrow geographical area. An example of such a wave

might be a coordinated attack on DDGA by enemy air and enemy surface and/or mines, while at the same time requiring the DDGA commander to conduct a search and rescue or a SCUD task! This would create an overload condition for the targeted DM in the D organization. But since these tasks are spread over several functional areas, players in the F organization would share the processing load, and so this "wave" would be relatively easier to process by the F organization.

There were approximately 8-10 such multi-functional waves created within scenario f, each wave lasting for about 200sec. We attempted to have each player node in D experience two such waves over the course of the game. As was the case in building scenario d, the waves often coincided with time critical (pop-up or UT) tasks especially if those tasks added an additional required resource category to the "mix".

One advantage of the F organization is that one DM owns all the assets to process a large class of tasks. No negotiation is needed among DMs as to who will perform which task and with which asset, as would be the case in a D organization with overlapping areas of responsibility. To force the need for players in D to coordinate, the flight paths of enemy SCUD-launched missiles were crafted to "boundary split" the areas between adjacent DMs, as were the paths of several surface threats, and the locations of enemy missile sites. In such cases inter-DM coordination is needed within D to most efficiently apportion the team's scarce assets ("who will do the task"), but such coordination is not needed in F.

6.4 Equivalence between Scenarios f and d

The testing of congruence involves comparing the performance on scenario d between organization D (congruent) and F (incongruent). The reverse comparison holds for scenario f. It has been suggested that the experiment could also provide a comparison between performance on scenarios f and d when performed by a single organization (D or F). This type of cross-scenario comparison depends on having some "equivalence" between the two scenarios in terms of difficulty, workload, etc. Clearly, if scenario f was significantly "easier" than scenario d, then comparison of performance between the two could not readily be ascribed to an organizational dimension.

The two scenarios do have a common task graph, primarily to ease the training requirements that were deemed to be excessive if players had to learn two entirely different task graphs. Since the two scenarios are markedly different in their task resource requirements, it was not clear how to operationalize "equivalence". One could talk about numbers of tasks, but this is not a realistic mode of comparison as tasks are quite different – except possibly for the self-defend tasks. Instead, we attempted to equalize the scenarios by adjusting the number of tasks in each scenario such that the total resource demands summed over all tasks would be roughly the same. This is computed by summing each resource category ri over all scenario tasks that have ri in their resource requirement vector. These comparisons are shown in Table 6.

scenario	AAW	Mines	ASuW	BMD	Strike	SAR	SOF
f	39	10	34	20	75	16	13
d	49	9	34	20	69	16	13

Table 6: f and d scenario comparisons

The numbers are equivalent for Mines, ASuW, BMD, SAR and SOF categories. Scenario f has greater Strike requirements, while d has higher AAW requirements. It must be noted however that the cross-functional requirements within the tasks themselves are absent from such a comparison – the coordination demands that this places on an organization is, of course, a function of both the scenario and the organizational structure.

7. Conclusions

This paper presented the details behind the design of two scenarios that were used in a team-in-the-loop experiment to test organizational congruence. A unique aspect of this work was the "reverse" engineering process used to design scenarios d and f, starting with the definitions of two very different organizational structures D and F. A second aspect of the work involved the use of the analytical models that predict the degree of fit (or congruence) between an organization and the mission it faces. These model predictions guided – at virtually every step – the selection of task requirements, locations, task graph dependencies, etc., that in total define a scenario. Iteration between the modelers and the experimenters in our design team helped assure that the scenarios to be tested in the laboratory would be both

reasonable/believable *and* model-driven to enable subsequent model-data comparisons.

A major congruence metric (of among several) is the degree of inter-node coordination. As this coordination is a function of the organizational structure *and* the mission/task requirements the scenario design process focused considerable effort on the selection of task resource requirements. Tasks in the congruent situations (Ff and Dd) were designed to require low inter-node coordination, whereas in the incongruent cases (Fd and Df) tasks were designed to have higher coordination demands. The tasks used for this instantiation included the major mission tasks, time-critical high priority tasks, and several others. Another metric that enters into congruence is workload imbalance. By adjusting the spatial and temporal arrivals of the tasks that dealt with defending against the enemy, we were able to differentially load individual nodes within either the D or F organizations, and unevenly load the team in the incongruent cases yet *for the same scenario* have a balanced/distributed workload in the congruent cases. Other, less salient manipulations in the scenarios were also effected (e.g., boundary splitting, information flows, situational awareness) that were geared to make the incongruent cases relatively more difficult than the congruent case. In short, we used the knowledge gained from earlier laboratory-based experiences along with guidance from model predictions to design the scenarios and "tune" the organizations.

Experiment 8 was conducted in August and November 2002 at the Naval Postgraduate School using eight teams. Four teams were organized as D and four as F, and each team was exposed to the f and d scenario twice, in counterbalanced order. A companion paper [Diedrich et al, 2003] describes results that convincingly show that *performance* in the congruent cases significantly exceeded that in the non-congruent cases. Some of the measures used to assess performance include number of tasks accomplished, accuracy, timeliness/latency. Having firmly established the value of congruence as a construct in "optimal" organizational design, our next step in our A2C2 research will be to examine the processes that teams employed to try to overcome poor performance in the incongruent cases, whether players were aware of any factors that caused their performance decrement, and what *human* teams are likely to do about it: e.g., adapt their structure (roles/responsibilities/assets) or just cope?

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